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13. ABSTRACT *(Maximum 200 words)*

The construction of a new stack geometry for thermoacoustic engines, called a "pin stack", is progressing. The stack is at the heart of a class of heat engines that use sound to deliver refrigeration, or use a temperature difference to generate sound. Calculations show that the pin stack should make useful improvements in engine efficiency. About 2300 wires are being hand sewn in a nearly hexangonal lattice between hot and cold heat exchangers. Accuracy of the placement of the wires is on the order of 10-20%. It was found, through simulation, that the pin stack is more sensitive to operating conditions than is a conventional stack.

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ONR Annual Summary Report
Thermoacoustic Pin Stacks
N0001495WR20001
July 1995
Robert M. Keolian, PI

Submitted to: DR LOGAN E HARGROVE ONR 331
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Description of Project:

The primary objective of this research is to construct and test "pin stacks." This stack geometry is predicted to substantially improve the efficiency of thermoacoustically based refrigerators, heat pumps and prime movers. Secondary objectives include the exploration of the desirability and practicality of fractal heat exchanger designs and of parametric sound sources.

Approaches Taken:

A comparison of the pin stack geometry with the conventional rolled geometry will be made in a modular prime mover test rig which uses low pressure neon gas held between room and liquid nitrogen temperatures. The stack is being constructed by hand sewing a constantan wire back and forth about 2300 times between the hot and cold heat exchangers. A small acoustic driver has been added to the rig to allow us to measure the quality factor *Q* below onset as a function of neon pressure. The performance of the pin stack will also be compared to the theory for pin stacks, developed by Greg Swift of Los Alamos National Laboratory, as incorporated in the program DeltaE [Ward and Swift, J. Acoust. Soc. Am. 95, (6), 3671-3672 (1994)].

Accomplishments Completed:

During the previous reporting period, 6/93-5/94, the program DeltaE was run with the conventional rolled stack geometry used in previous experiments on this rig, in order to make sure that we can get the program to agree with experiment. Also, a series of DeltaE runs using pin stacks was made to increase our understanding of pin stacks and to optimize the test stack's dimensions. A wire size r_i of 75 microns with a spacing $2y_0$ of 750 microns, in a nearly hexagonal lattice pattern fitting nicely on the heat exchangers, was selected, as shown in figure 1.

This reporting period, 6/94-5/95, we learned an interesting bit of intuition from our DeltaE calculations: As shown in figure 2, the pin stack is considerably more sensitive than the conventional stack to changes in parameters—such as stack element spacing or size, mean operating pressure or temperature—because you lose for the same reason you win. You win with the pin stack because of the good volume–bad volume argument: The ratio of the good volume (at around a thermal penetration depth from the stack element) to the bad volume (within around a viscous penetration depth) goes approximately as the square of the ratio of the thermal to viscous penetration depths in the pin stack, but only goes linearly in the ratio of the penetration depths for the conventional stack. However, there is another "volume" in the problem—the total volume. You loose with the pin stack because the ratio of good volume to total volume also goes as the square of the thermal penetration depth for the pin stack, whereas it only goes linearly with the thermal penetration depth in the conventional stack. In response to an increase in the mean operating pressure, as shown for example in figure 2, the penetration depths decrease. The difference between the total volume and the good volume can be considered to be "useless volume," and this useless volume increases a lot quicker with the pin stack than with the conventional stack, decreasing performance at higher mean pressures. A short paper on this point is in preparation.

Our experimental pin stack cell has glass side walls so that we can see how well the construction of it is going, and so we can conduct nonlinear Laser Doppler Velocimetry experiments in the cell at a later date. Along with my student, LT Scott Nessler, we test cooled the first version, without a pin stack, in liquid nitrogen. The glass shattered because I was not compulsive enough about differential contraction

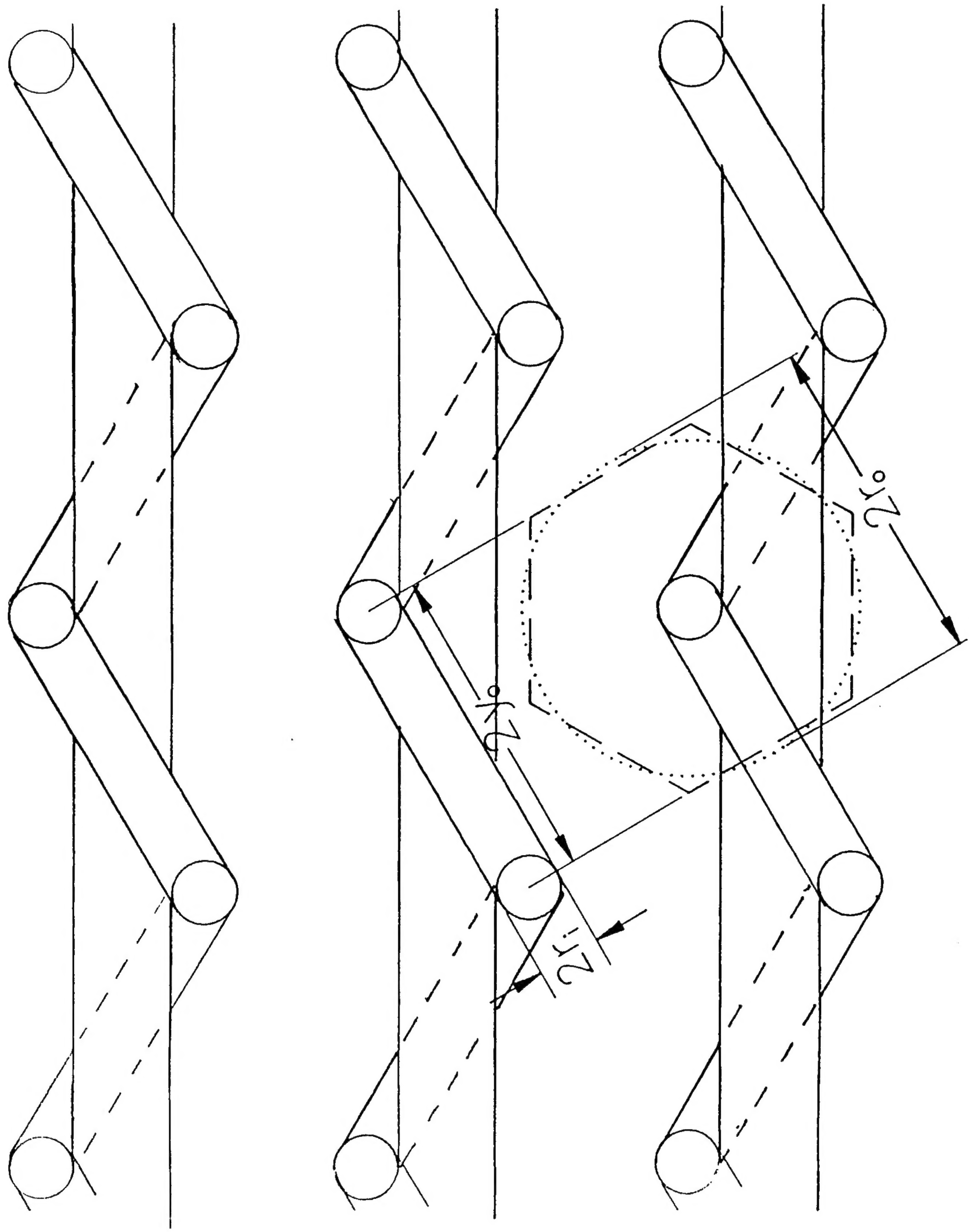
calculations. Our second version is made with Teflon gaskets to relieve some of the stresses, and it has cooled successfully.

Winding the pin stack has been a thoroughly miserable project. Scott, who is pretty good with his hands, thought he could hand sew it, but it proved to be too difficult to keep the needle going to the correct slots that were cut in the heat exchangers to accept the wire. We have since constructed "Bulwinkle," a complicated Rube Goldberg jig so named because of its odd looking ears that guide the needle and wire into the proper position. With it I have sewn (it is probably too difficult for a student) 230 of the 2300 wires with 18 (8%) of the wire ending up in the wrong slot. The machine has gone through many revisions trying to bring the error rate down so that a quantitative test with the theory can be performed, and the later windings are better than the first. There are also about 10% errors in the positions of the good wires due to uneven tension on them as they bend around the heat exchange fins, but this too has improved. Additionally, there is a systematic error in the wire positions. Our pattern deviates from an ideal hexagonal lattice near the heat exchangers by about plus/minus 40%, but is quite good halfway in between. The various errors are correlated, however. The total amount of wire is correct, so that when two wires are too close together, another pair are too far apart, compensating somewhat. We are hoping to model this by taking a weighted average of DeltaE results with various pin spacings. Clearly it would be better if industry, instead of us, would make the pin stacks, and some of this transitioning is also occurring.

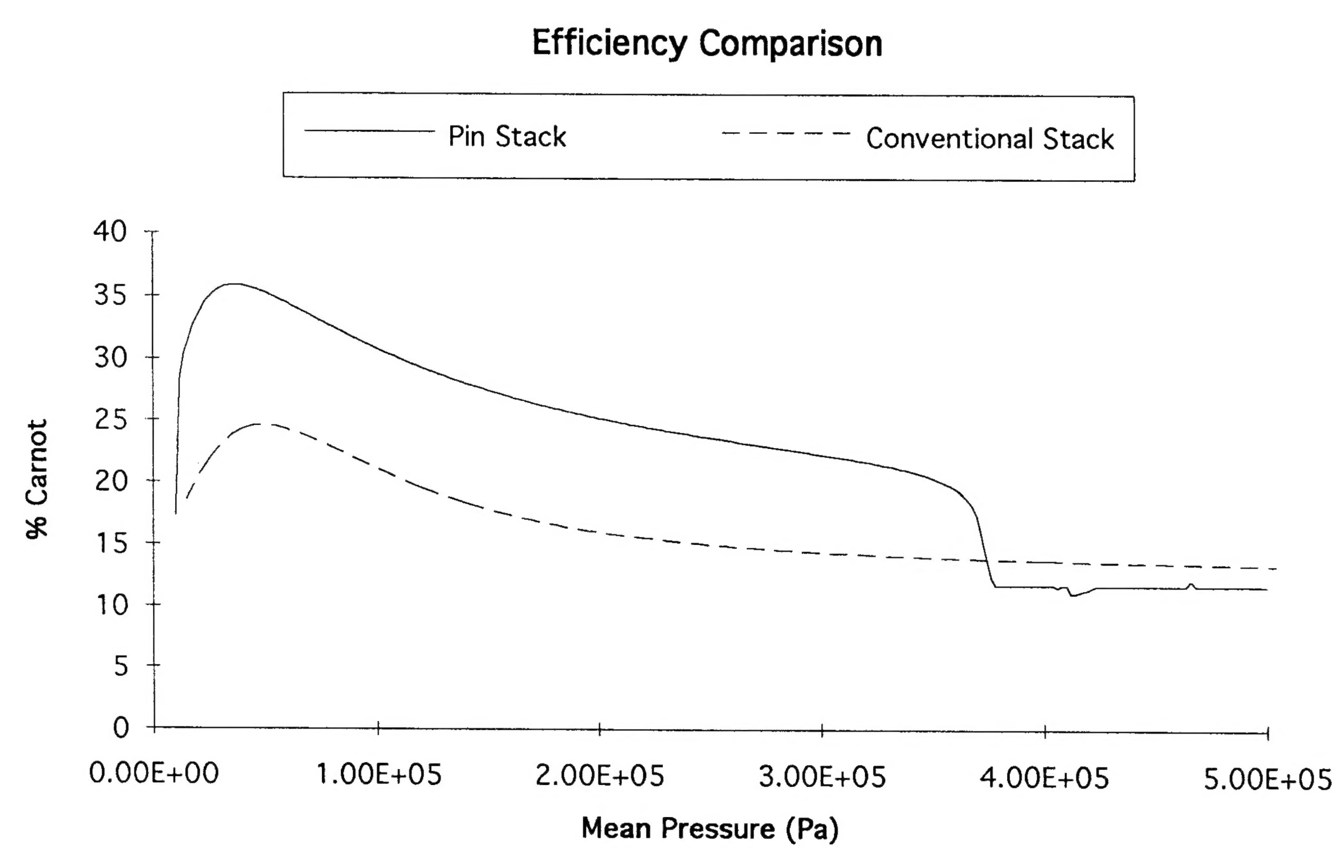
Tom Hofler, Jay Adeff, Anthony Atchley and I are also collaborating on the construction of a large heat driven thermoacoustic refrigerator—a keg cooler. My main contribution will be to make poor man's pin stacks with Fiberglas, using DeltaE to calculate optimal pin spacings with Fiberglas fiber sized pins, and using this knowledge to adjust the density of the Fiberglas batt.

Students Associated with Grant:

LT F. Scott Nessler, USN, has conducted his M.S. thesis work on this project.



$2r_o$
$2r_o$
$2r_i$


Efficiency Comparison
Pin Stack
Conventional Stack
% Carnot
40
35
30
25
20
15
10
5
0
0.00E+00
1.00E+05
2.00E+05
3.00E+05
4.00E+05
5.00E+05
Mean Pressure (Pa)

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PUBLICATION/PATENTS/PRESENTATION /HONORS REPORT
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a. Number Of Papers Submitted to Referred Journal but not yet published: __0__

b. Number of Papers Published in Referred Journals: __0__
(list attached)

c. Number of Books or Chapters Submitted but not yet Published: __0__

d. Number of Books or Chapters Published: ___0__
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f. Number of Patents Filed: __0__

g. Number of Patents Granted: __0__
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h. Number of Invited Presentations at Workshops or Prof. Society Meetings: __0__

i. Number of Presentations at Workshops or Prof. Society Meetings: __1__

j. Honors/Awards/Prizes for Contract/Grant Employees: __0__

k. Total number of Graduate Students and Post-Docs Supported at least 25%, this year on this contract, grant:

Grad Students __1__ and Post Docs __0__

Grad Student Female	__0__
Grad Student Minority	__0__
Grad Student Asian e/n	__0__
Post-Doc Female	__0__
Post-Doc Minority	__0__
Post-Doc Asian e/n	__0__

P3H Publications:

e. Technical Report and Non-Referred Papers:

F. Scott Nessler, "Comparison of a pin stack to a conventional stack in a thermoacoustic prime mover," M.S. Thesis, Naval Postgraduate School, Monterey, CA, December 1994

i. Contributed Presentations:

F. Scott Nessler and Robert M. Keolian, "A thermoacoustic pin stack," *J. Acoust. Soc. Am* **96,** No. 5, Pt. 2, Nov. 1994.